

The PHENIX Resistive Plate Chamber Forward Upgrades

Outline

- Motivation / Measurement Method
- Trigger Needs
- Instrumentation
- Trigger Details
- Offline Analysis Challenges

Andrew Glenn

University of Colorado, Boulder
for the PHENIX Collaboration



23rd WWND Feb 14, 2007

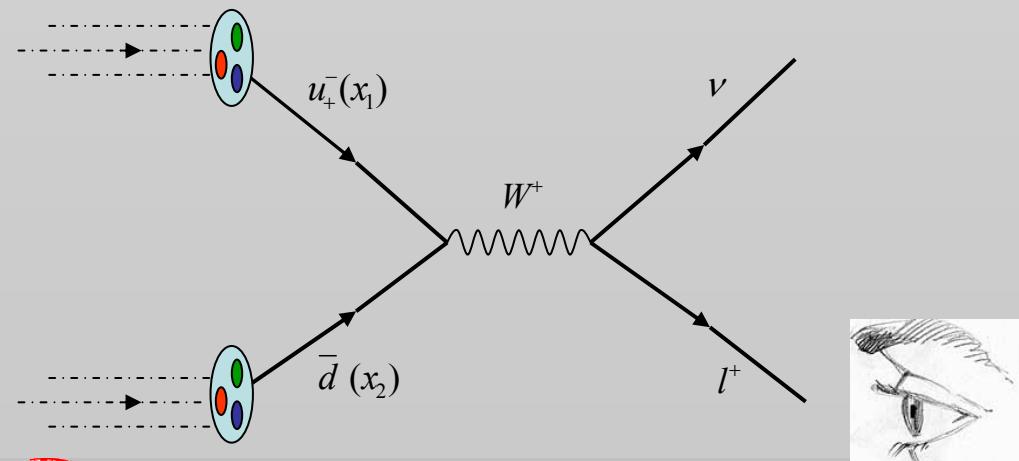
Motivation

- The sea quark polarizations of the proton can be probed through the single spin asymmetry, A_L , of the W^+ and W^-
- The PHENIX collaboration plans to determine A_L and σ for W^+ and W^- bosons at forward and backward rapidities in $p+p$ collisions at 500 GeV.
- In a $p+p$ collision, two quarks will interact at two Bjorken momentum fractions (x_1 and x_2) and produce a W boson.

$$u + \bar{d} \rightarrow W^+$$

$$\bar{u} + d \rightarrow W^-$$

- PHENIX will look at the cases where the W decays to a muon and a neutrino. It will be able to detect the muons but not the neutrino.

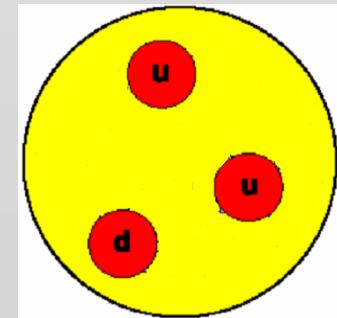


Method Details

- Using the number of muons detected at forward and backward rapidities, A_L can be calculated using:

$$A_L^{W^+} = \frac{1}{P} \times \frac{N_-(W^+ \rightarrow \mu^+) - N_+(W^+ \rightarrow \mu^+)}{N_-(W^+ \rightarrow \mu^+) + N_+(W^+ \rightarrow \mu^+)}$$

$$A_L^{W^-} = \frac{1}{P} \times \frac{N_-(W^- \rightarrow \mu^-) - N_+(W^- \rightarrow \mu^-)}{N_-(W^- \rightarrow \mu^-) + N_+(W^- \rightarrow \mu^-)}$$



- We could simply compare A_L to models but, the sea quark polarizations of the proton can be probed **to first order** through A_L using:

$$A_L^{W^+} = \frac{\Delta u(x_1)\bar{d}(x_2) - \Delta \bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}$$

Large x_1

Large x_2

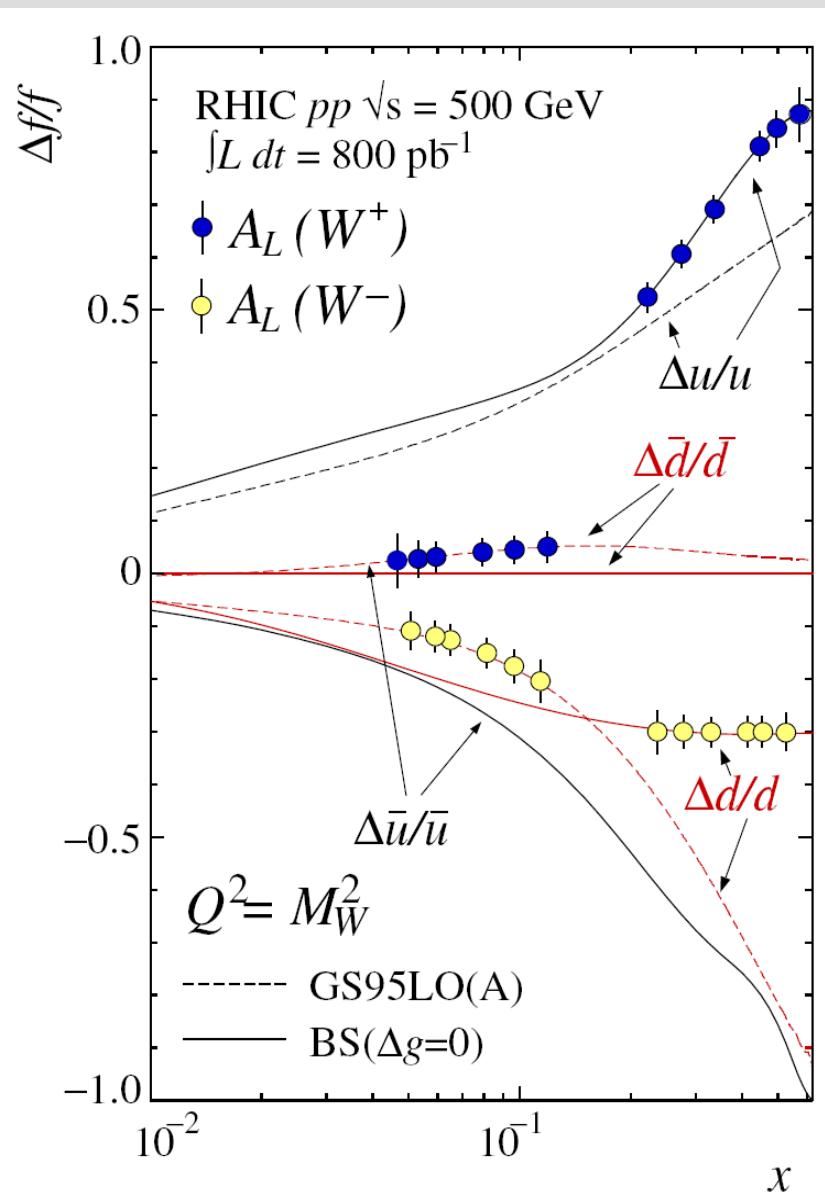
$$A_L^{W^-} = \frac{\Delta d(x_1)\bar{u}(x_2) - \Delta \bar{u}(x_1)d(x_2)}{d(x_1)\bar{u}(x_2) + \bar{u}(x_1)d(x_2)}$$

Large x_1

Large x_2

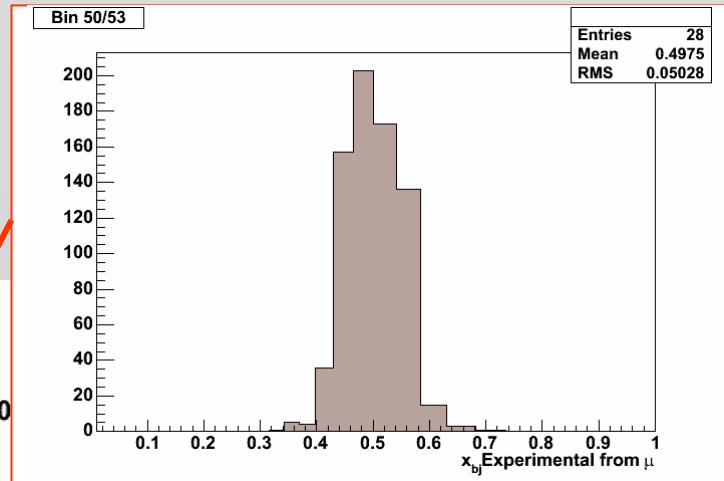
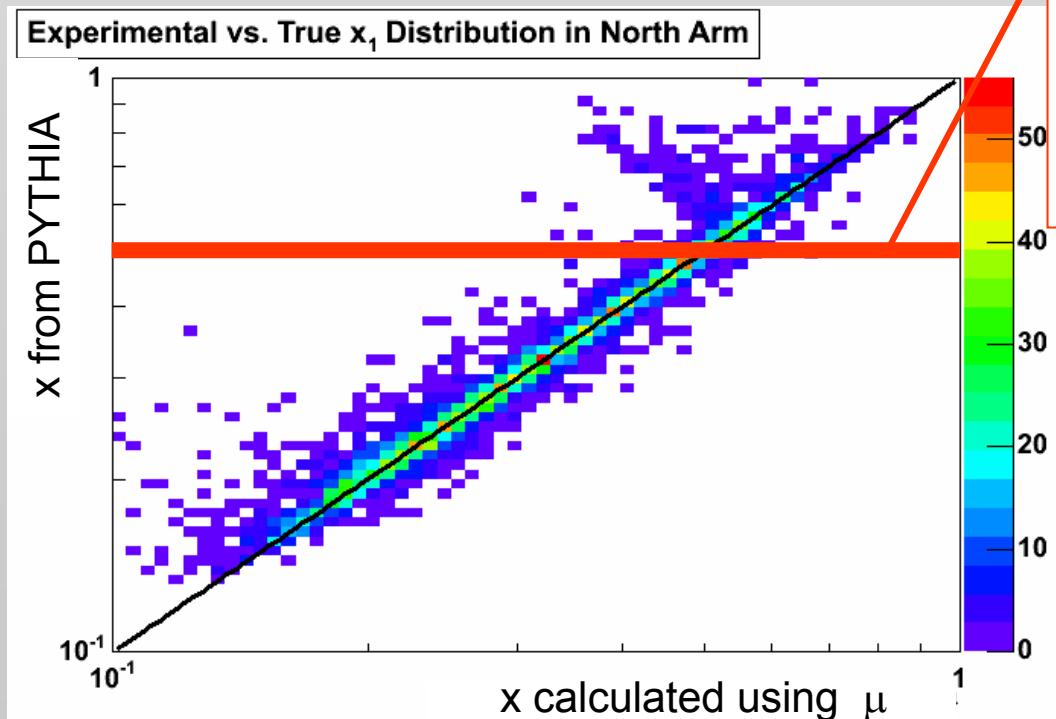
Sensitivity

- In *Bunce et al, Prospects for Spin Physics at RHIC, Annu. Rev. Nucl. Part. Sci. 2000*, the sensitivity to the sea quark polarizations were calculated.
- The sensitivity is calculated from the number of muons detected as a function x_1 and x_2 .
- The *Bunce et al.* paper, **assumes** the p_T of the W is zero which allows for a one-to-one correlation between measured μ kinematics and the true W kinematics.



Smearing from W p_T

- Because the neutrino can not be detected, the momentum of the W can not be completely reconstructed from the decay products causing a smearing in the momentum calculated for the W.
- Plotting the true x_1 value produced in PYTHIA versus the x_1 value that would be calculated from the muon, a smearing occurs in the correlation.



We will continue to study other effects such as going beyond leading order, reconstruction resolutions ...

PHENIX Trigger Needs

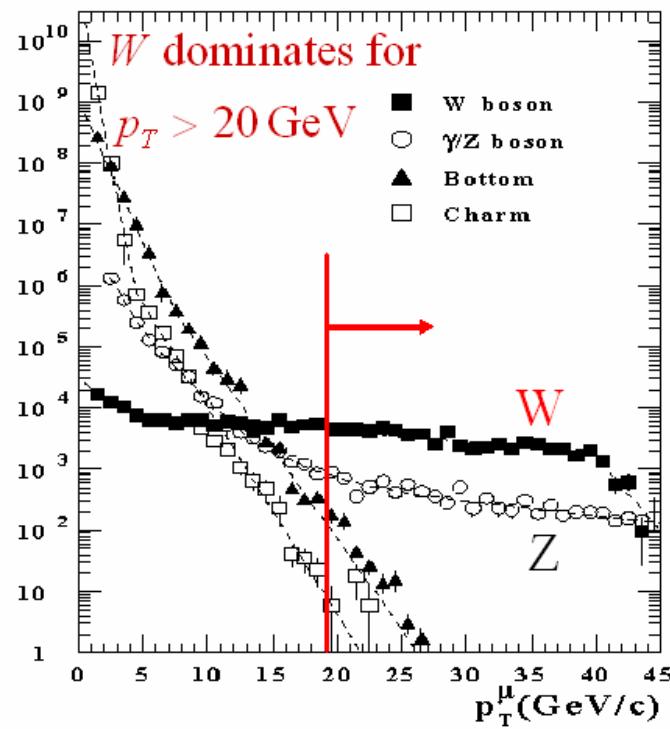
Design Luminosity

$\sqrt{s} = 500 \text{ GeV}$ $\sigma = 60 \text{ mb}$
 $L = 2 \times 10^{32} / \text{cm}^2/\text{s}$

Total X-sec rate = 12MHz

DAQ LIMIT
= 1-2kHz (for μ arm)

Inclusive μ Production, 500 GeV/c



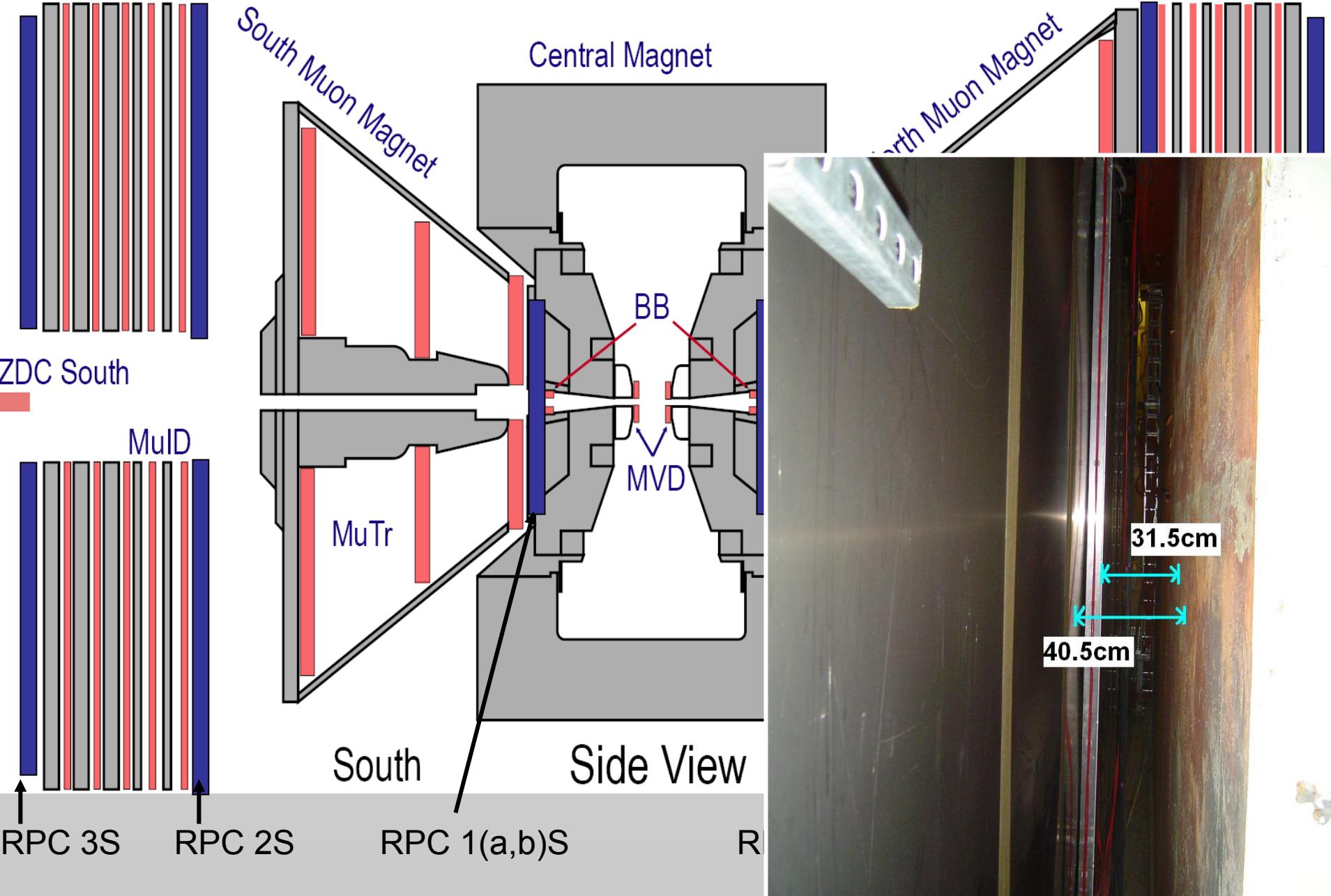
Required RF
~ 10,000

Current MuID LL1
has a RF of ~500
at 200GeV

Abilene Christian University, Brookhaven National Laboratory, University of California, Riverside, CIAE, University of Colorado, Columbia University/Nevis Laboratory, Georgia State University, University of Illinois, Iowa State University, Korea University, Muhlenberg College, Peking University

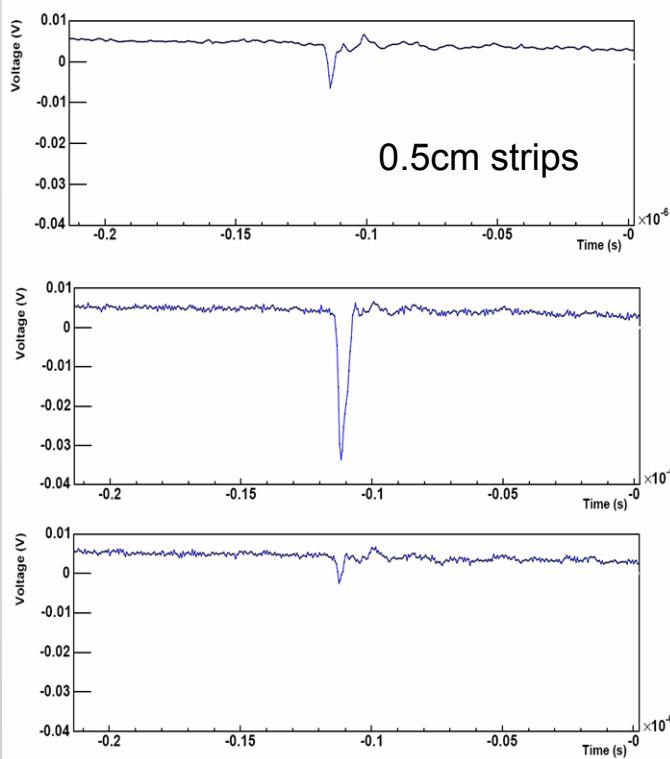
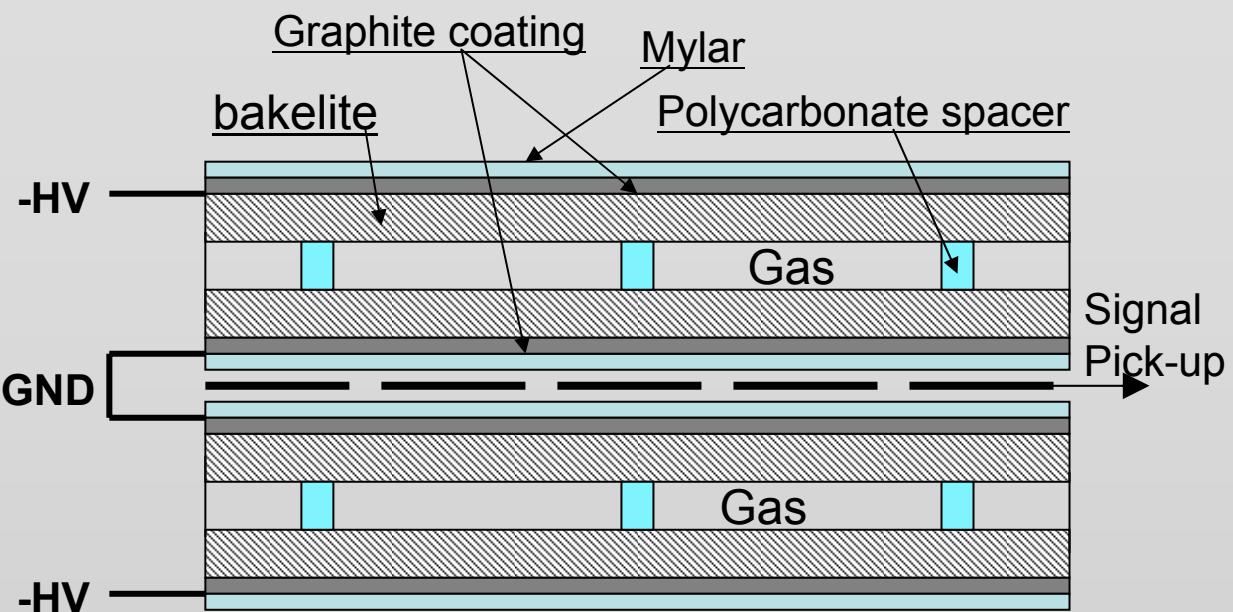
NSF Funded

Much of the manpower is DOE funded



Trigger should provide momentum selection and vertex pointing

Resistive Plate Chambers



- Good timing performance ($\sim 1\text{-}2\text{ ns}$)
- Good rate capability (\sim several kHz/cm 2)
- Space resolution ($\sim \text{cm}$)
- Simple design & low cost

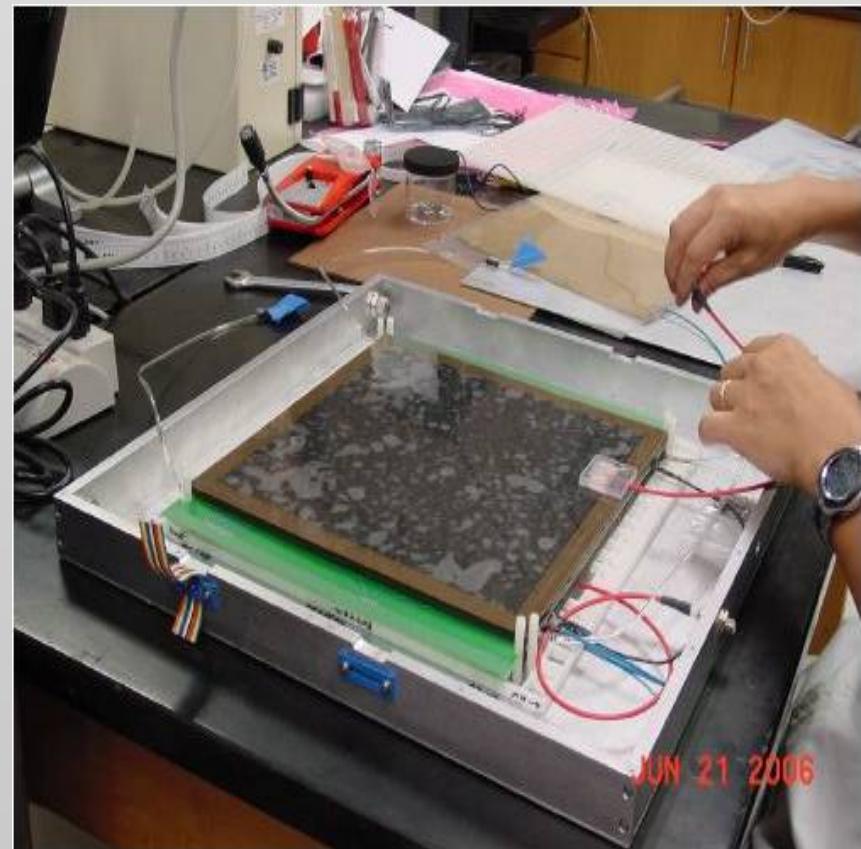
Typical gas mixture:
95%R134A + 4.5% ISO + 0.5% SF₆

WE ARE COPYING CMS

Developing Local Expertise

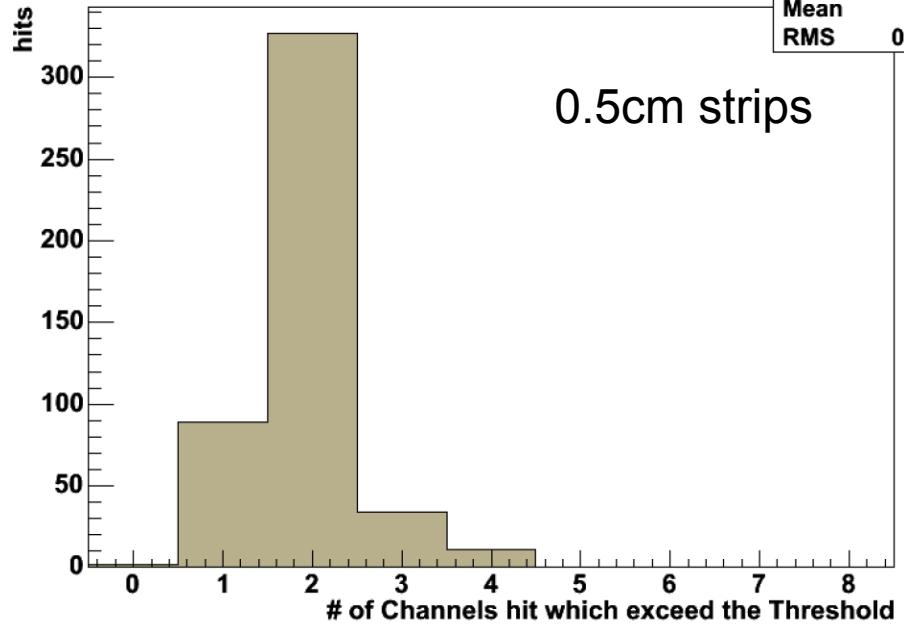
Test Stands at multiple institutions

GSU Built RPCs

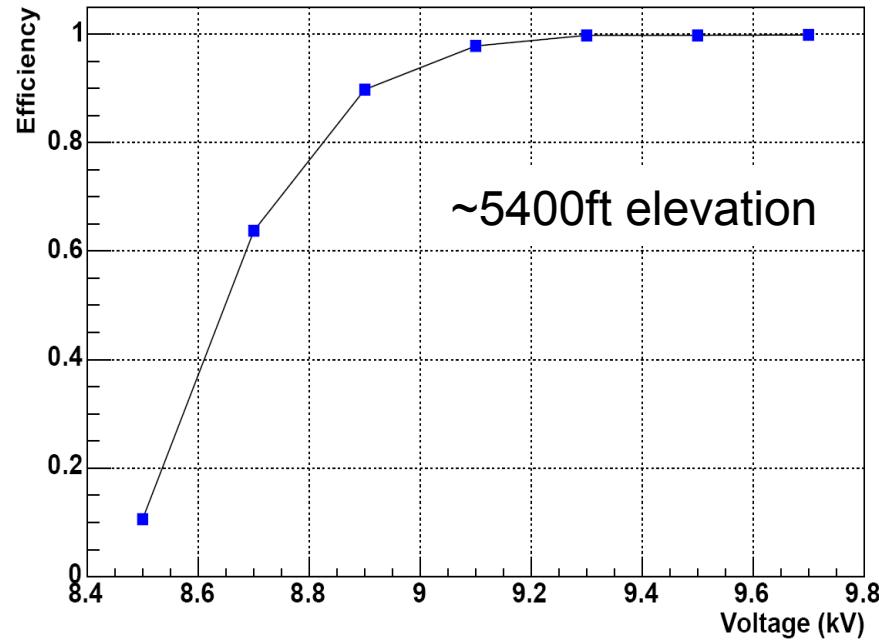


Test Stand Results

Strip with hits below $V_{th} = -0.004000$



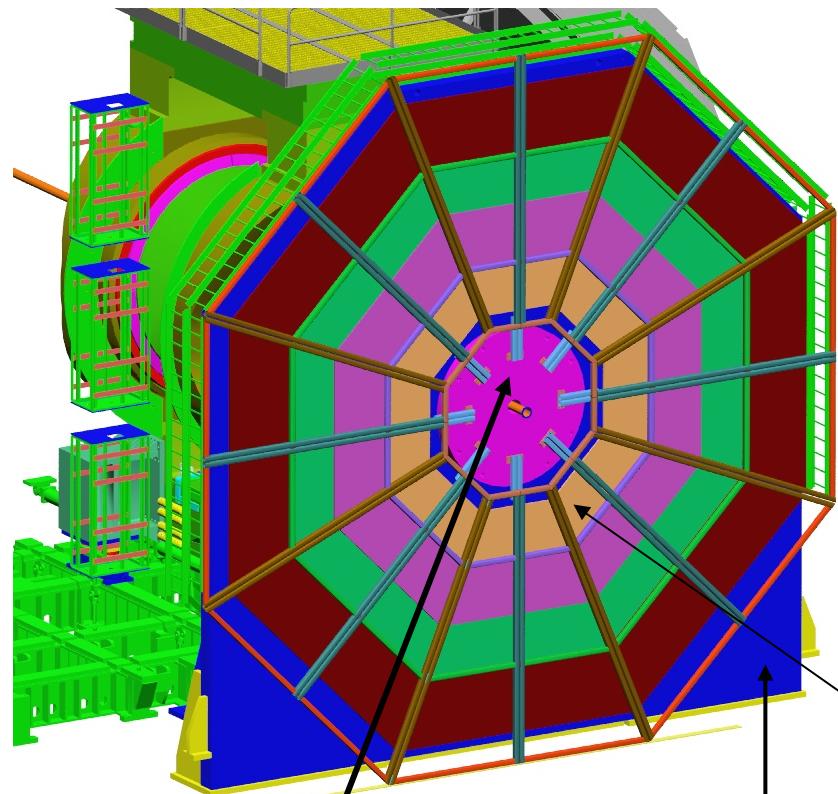
Double Gap Efficiency at 4mV Threshold



- Strips widths smaller than ~1cm are useless without ADC
- No \$\$ or plans for ADC (with more than one bit)
- Cluster distributions needed for trigger simulations

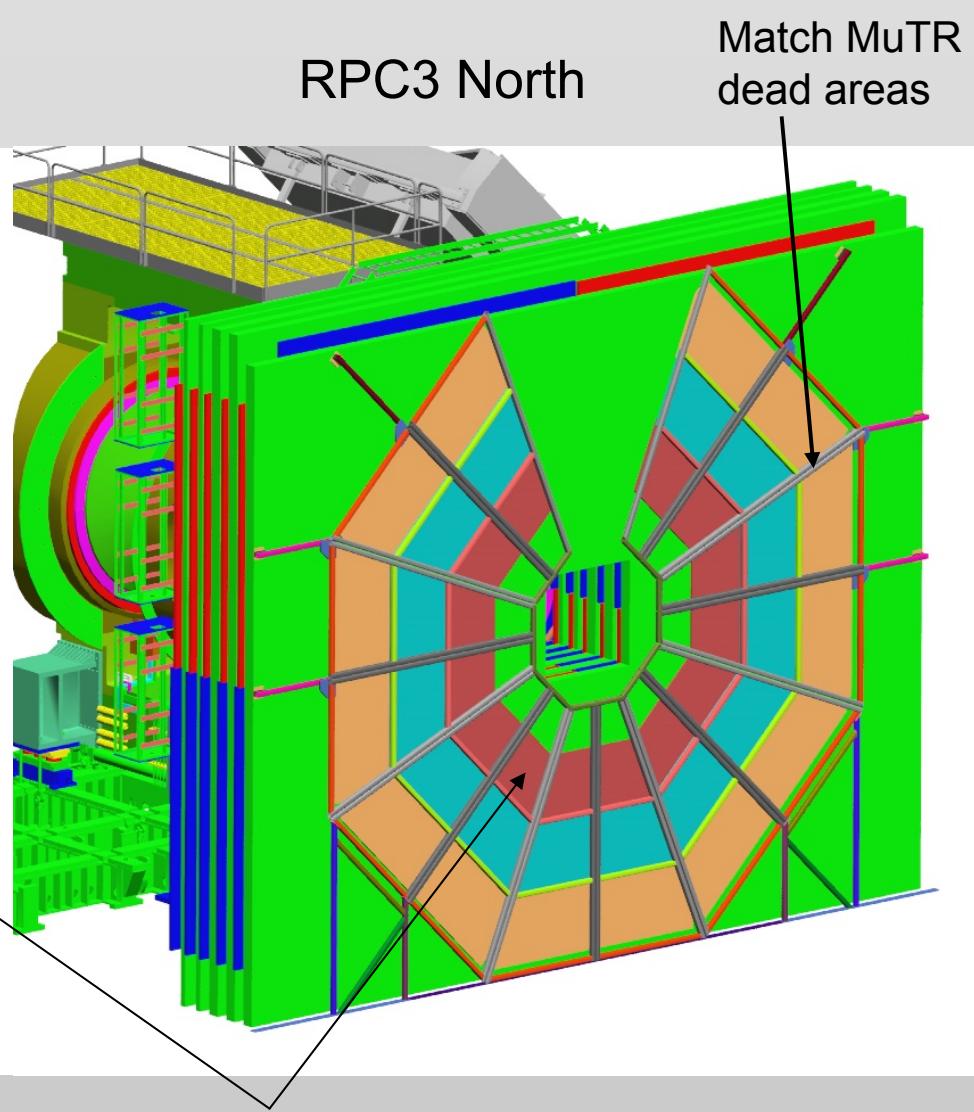
Detector Geometry

RPC2 North



Accessible from tunnel

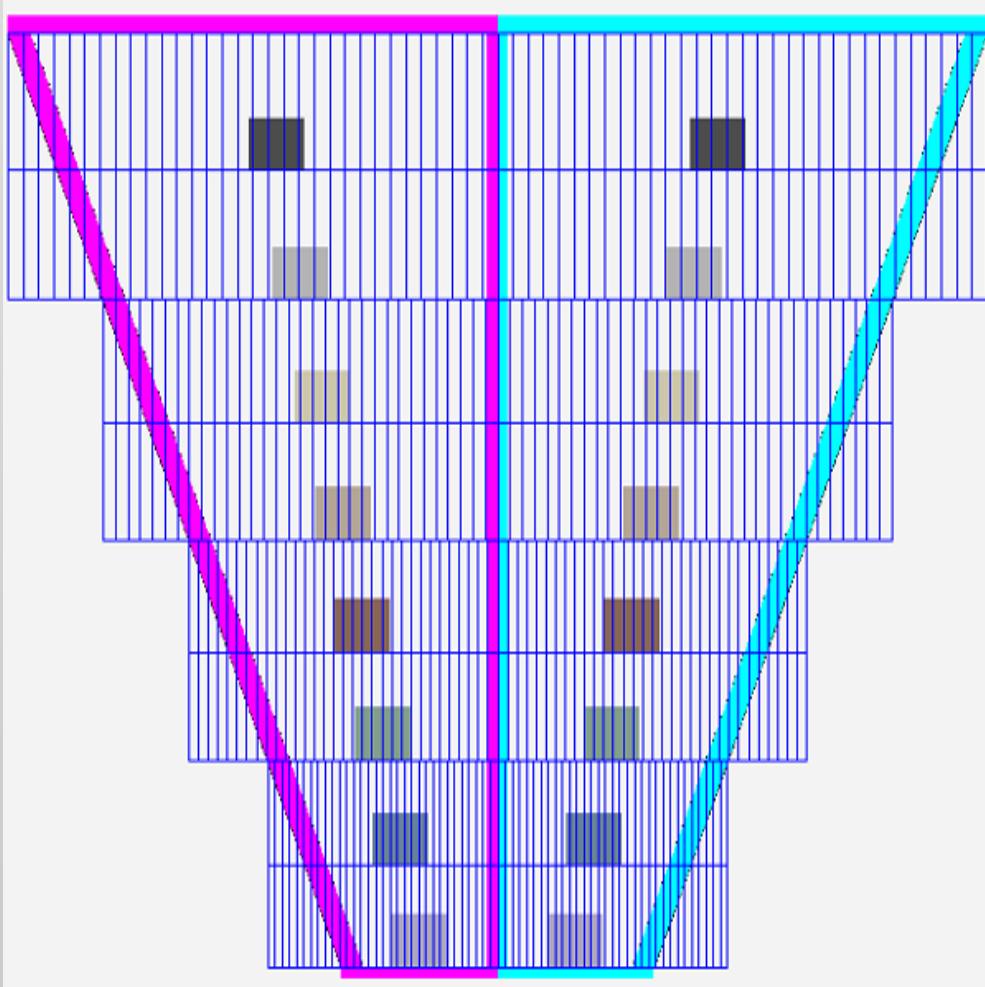
RPC3 North



"Rings" of equal η coverage

Readout Strip Geometry

RPC2 Octant



RPC2
strips: 467.9 x 60.5 (64)
strips: 441.0 x 60.5 (58)
strips: 418.2 x 48.8 (64)
strips: 298.9 x 48.8 (57)
strips: 382.7 x 38.2 (64)
strips: 369.1 x 38.2 (56)
strips: 357.8 x 28.4 (64)
strips: 354.7 x 28.4 (54)

Units of mm (channels)

	RPC1 a+b	RPC2	RPC3
Channels	3072	3848	2872

141.0 x 11.4 mm Inner RPC1
to
554.2 x 64.6 mm Outer RPC3

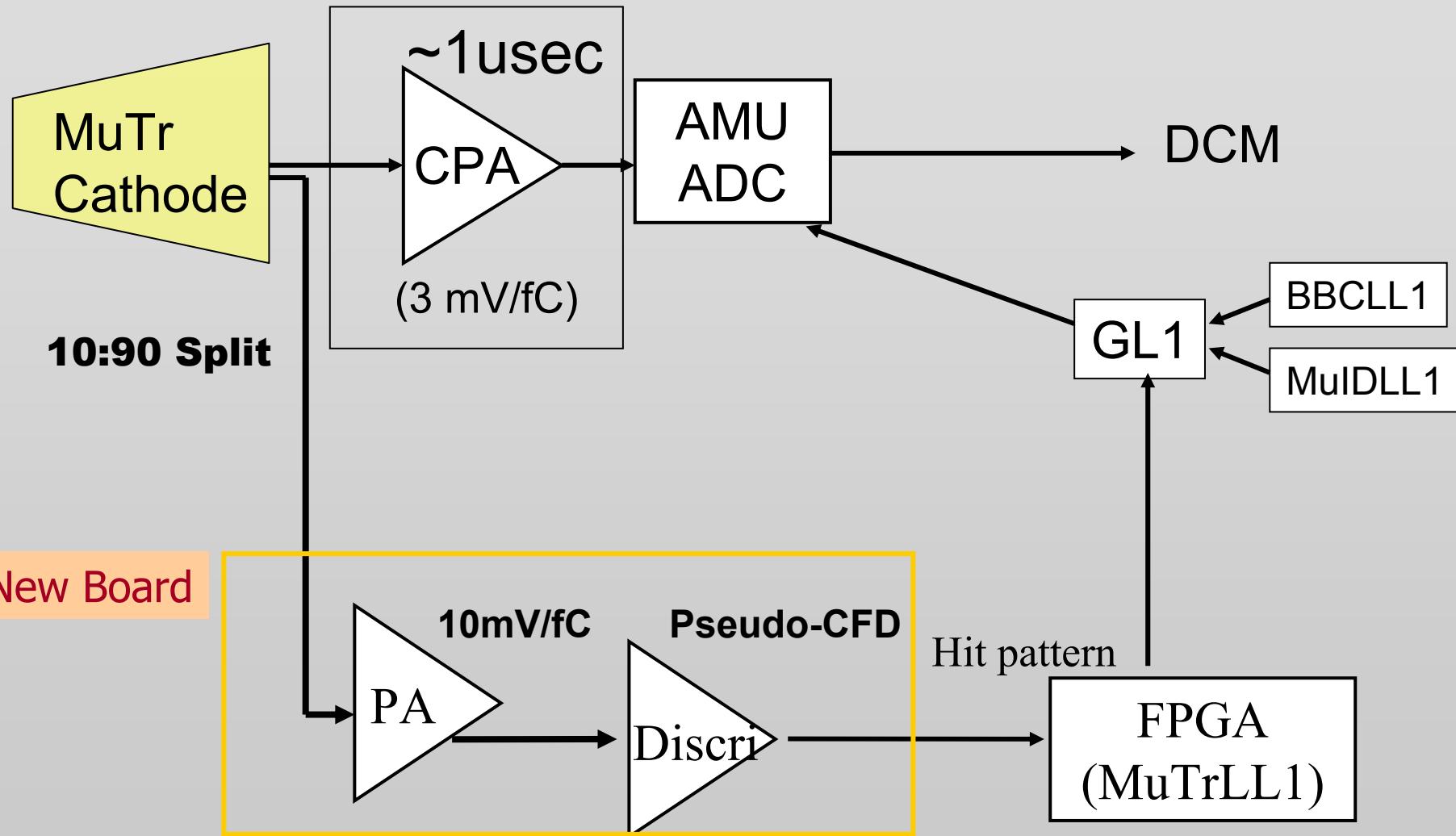
Octant and strip readout to be designed to complement MuTR

MuTR FEE Upgrade

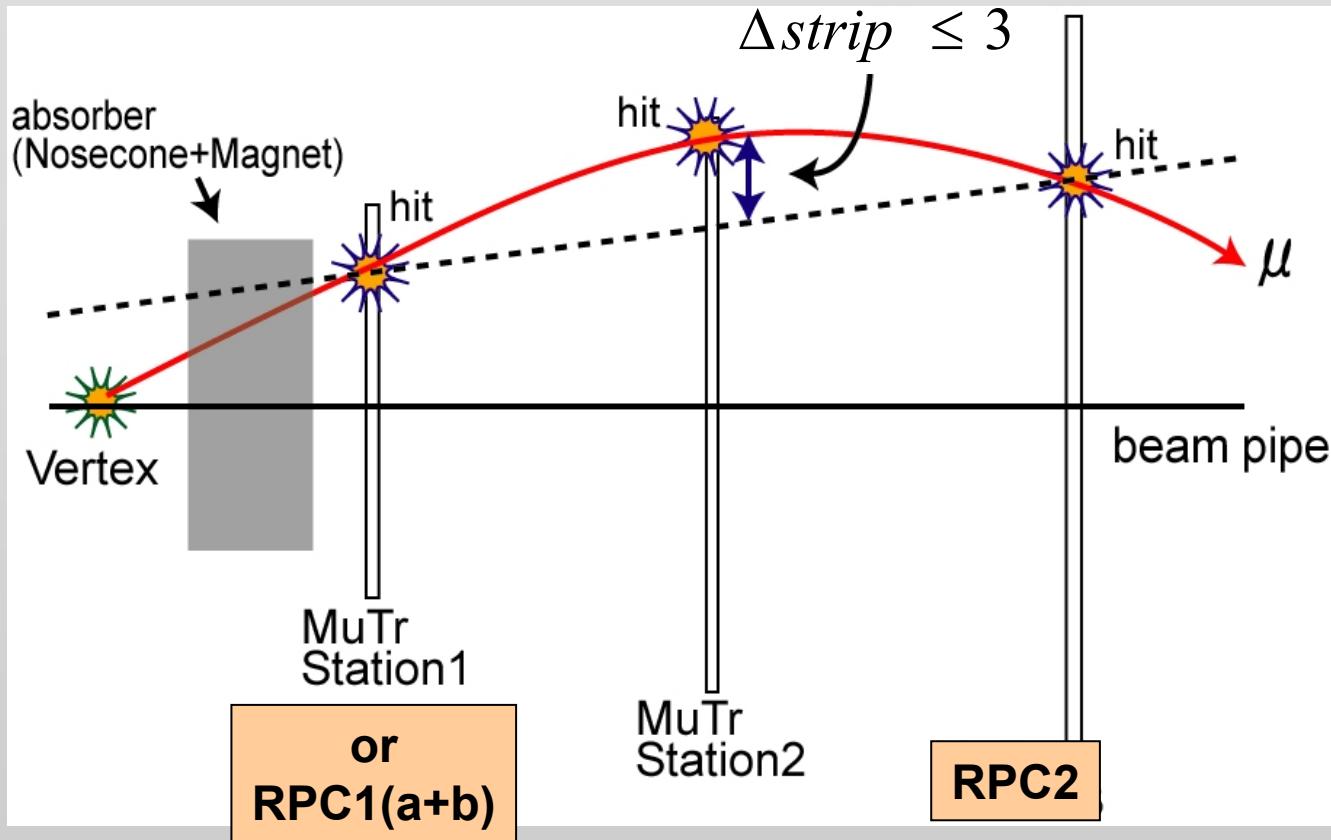
- Current MuTR Front End Electronics are too slow for Level 1 trigger
- New FEE will provide list of hit strips to Level 1 trigger
- Current plan is to instrument non-stereo plains in MuTR stations 1 and 2 for both arms
- Funding approved by JSPS

*Riken-BNL Research Center,
University of Kyoto,
Rikkyo University, KEK,
Los Alamos National Lab,
University of New Mexico*

MuTr FEE Modifications



Trigger Algorithm



Candidates found by matching RPC1/2 hits within angular range. Momentum cut made by matching hit in MuTr station 2 within three cathode strips of RPC projection.

Trigger Simulation Results

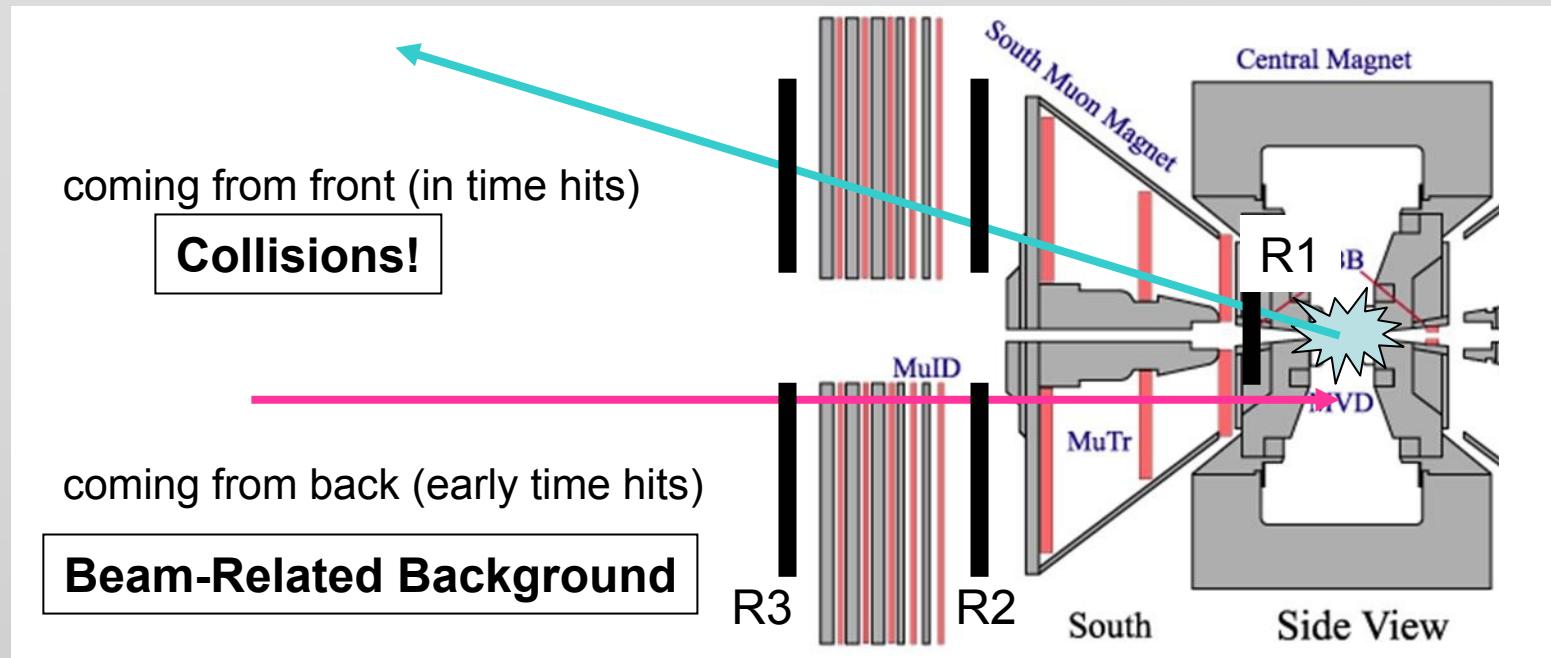
- Full GEANT simulation of PYTHIA events
- Use several variations of trigger algorithms (detector combinations) to rejection factors

RPC1/2 Angle Cut:	MuRPC+ST2 $ \Delta\text{strip} \leq 3$ NO CLUSTERS	MuRPC+ST2 $ \Delta\text{strip} \leq 3$ CLUSTERS	MuRPC+ ST1+ST2 $ \Delta\text{strip} \leq 3$ (RPC1->ST1)
3 degree cut	14,672 (1,780)	14,459 (1,740)	13,127 (1,506)

(Statistical errors shown in parenthesis.)

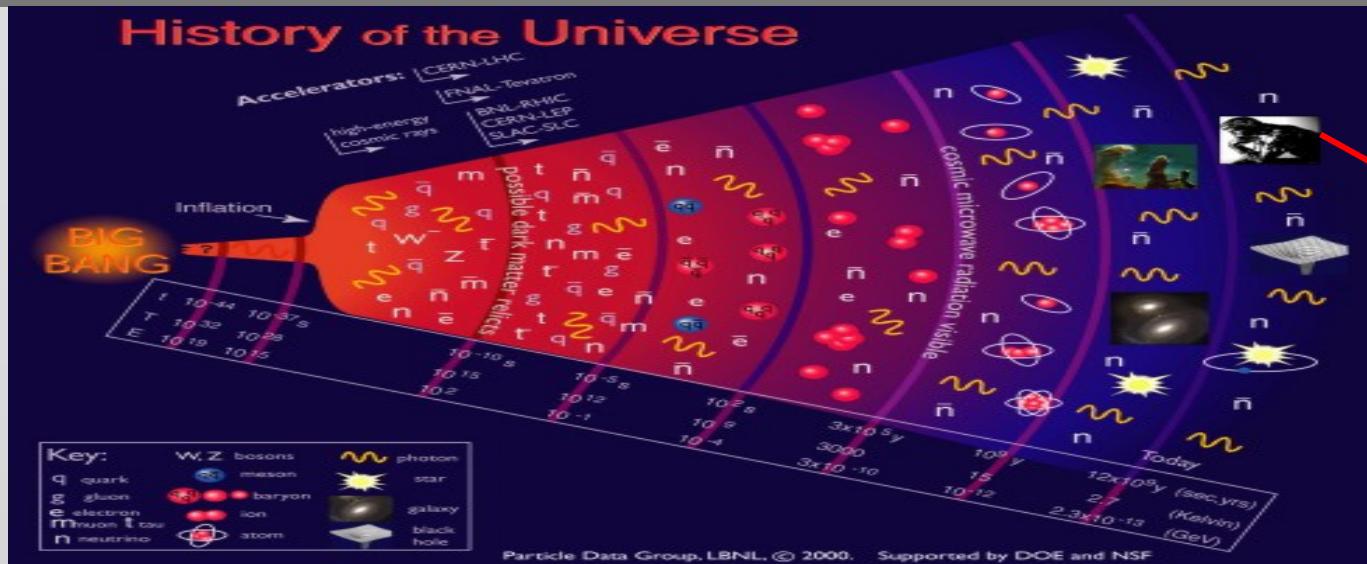
- Good efficiency for high p_T muons
- Based on $\sim 1M$ PYTHIA p+p events at $\sqrt{s} = 500\text{GeV}$.
- Rejection factors are combined for both muon arms.
- **USES SLIGHTLY DIFFERENT PAD READOUT**
- **All over the rejection goal of 10,000**

Beam-Background Rejection



- Severity of beam backgrounds at 500GeV (with high luminosity) is largely unknown.
- **RPC timing used to eliminate early-time hits.**
- Trigger rejection largely independent of beam-related backgrounds.

Time Line



	Summer 2007	Summer 2008	Summer 2009	Pre RHIC II
RPCs		RPC 3 North & South	RPC 2 North & South	RPC 1a,b
MuTR FEE	2 Octants of Stations 1+2 South	All of Stations 1+2 South	All of Stations 1+2 North	

Absorber may be added in RPC1's position matching MuTR FEE coverage/timetable.

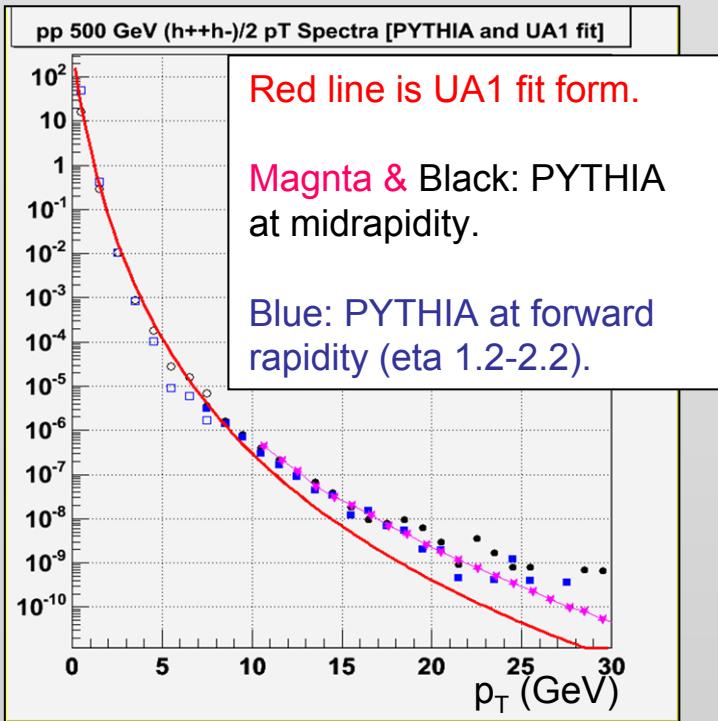
If so, it will be removed or reduced prior to installation in RPC1 a,b

Offline Backgrounds

- Triggering on W events is necessary but not sufficient. We should try to address all of the offline background issues we can before taking data
 - **Punch through**: Small fraction of high p_T hadrons which penetrate through the detector
 - **Fake High p_T** : Small fraction of low p_T hadrons which decay in the MuTR and are incorrectly reconstructed with high p_T

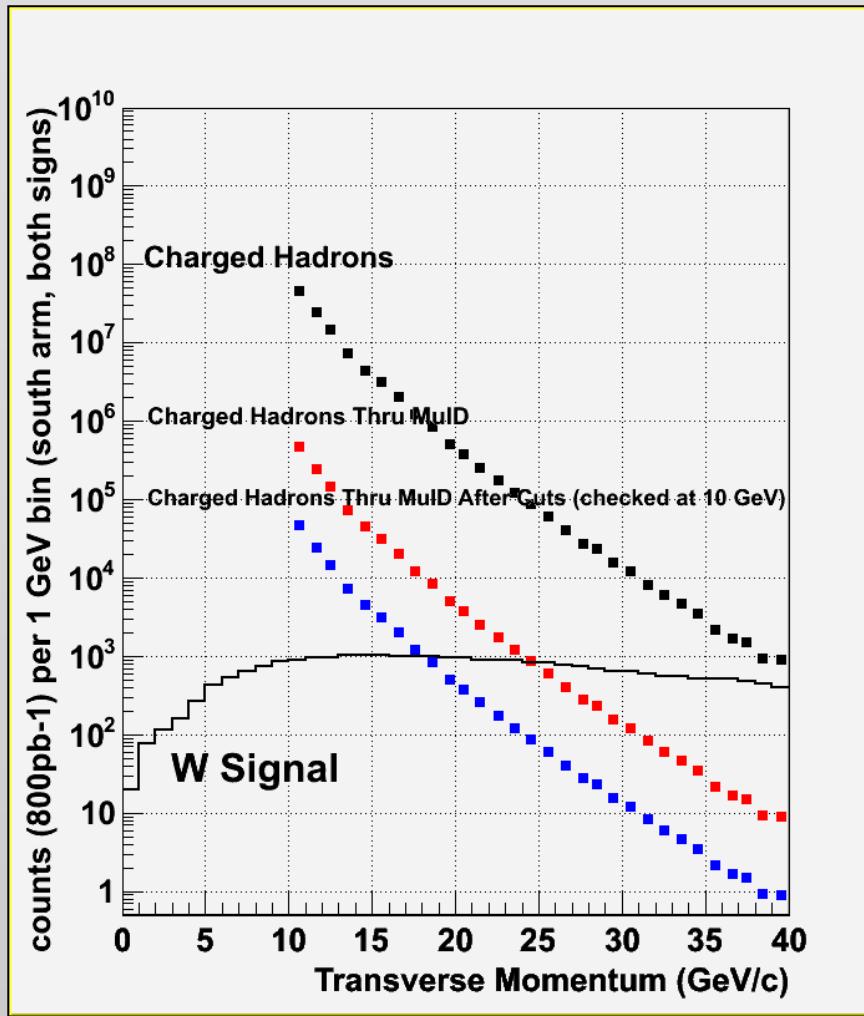
Punch through

Invariant Ed3sigma/dp3 (mb/GeV²)



Applying tight matching cuts substantially reduces the background for pions (and kaons) except irreducible fully penetrating category.

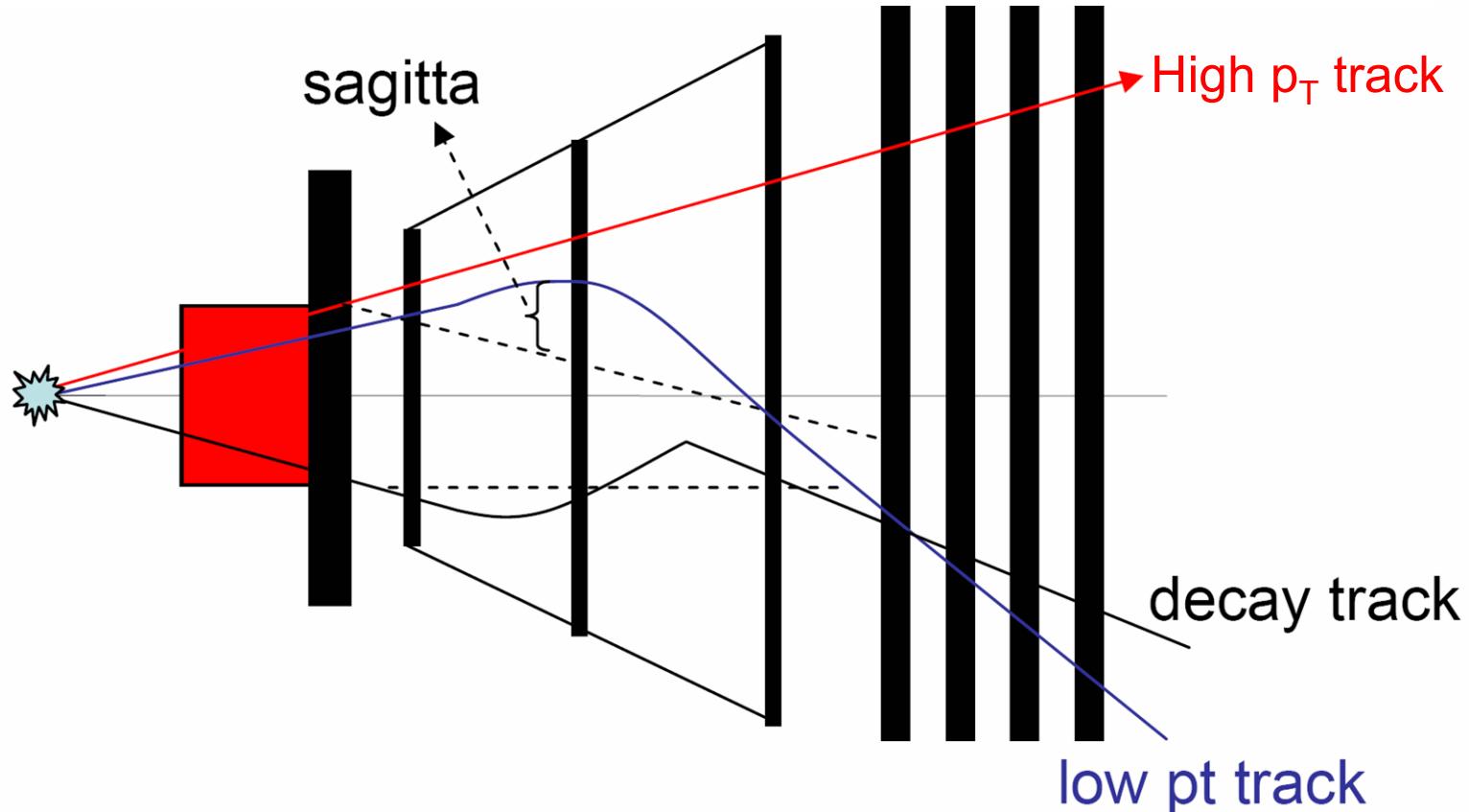
	10M input	10GeV	20GeV
$z \neq 0$ background		$45k \rightarrow 6k$	$62k \rightarrow 7k$
$z = 0$ true punch through		$1k \rightarrow 1k$	$1k \rightarrow 1k$
$z = 0$ punch + shower		$11k \rightarrow 3k$	$9k \rightarrow 2k$



Punch through should not be a major issue especially if any absorber is added

Fake High p_T

Hadron decays in the MuTR can make tracks appear straighter



Can be battled with:

- Tighter quality cuts / and inter detector matching
- Additional absorber (Tungsten from Nose Cone Calorimeter ...)
- Additional detectors (Forward Silicon Vertex detector)

Summary

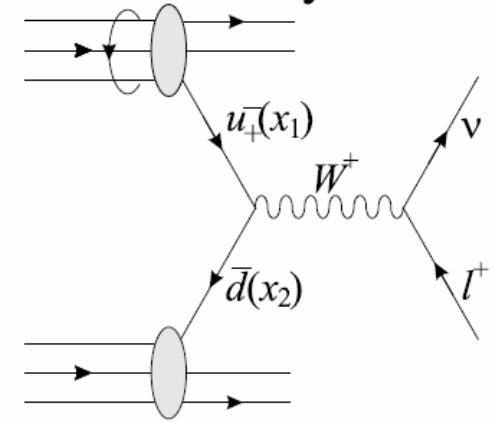
- The polarized proton program at RHIC will address two key missing pieces of information through $W^{+/-}$ production:
 - The antiquark spin structure functions
 $\Delta \bar{u}(x), \Delta \bar{d}(x)$
- The PHENIX Forward Upgrade will provide the event selection necessary to access this physics:
 - New RPC-based tracking chambers
 - New electronics for MuTr LL1 input
 - New Level-1 Muon Trigger electronics

Side Note on Heavy Ions

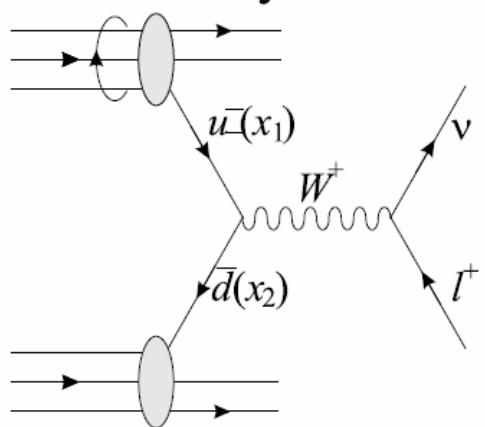
- RPCs may provide some reduction of combinatoric background in heavy ion collisions, but the pad sizes are too large to have a dramatic impact
- Studies are under way to see if the RPCs can help trigger on dimuons in A+A collisions at RHIC II.

EXTRAS

Proton helicity = "+"

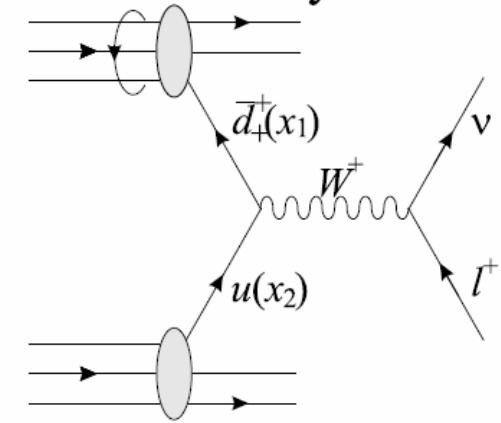


Proton helicity = "-"

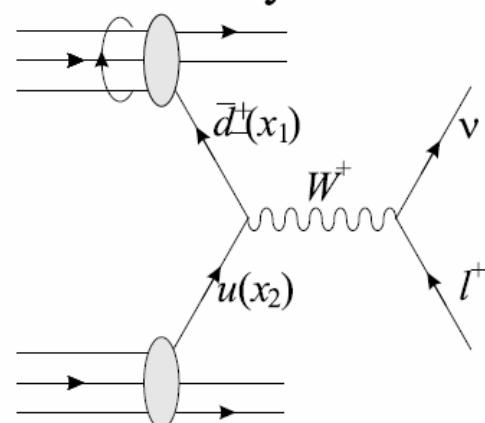


$$A_L^{W+} = \frac{u_-(x_1)\bar{d}(x_2) - u_+(x_1)\bar{d}(x_2)}{u_-(x_1)\bar{d}(x_2) + u_+(x_1)\bar{d}(x_2)} = \frac{\Delta u(x_1)}{u(x_1)}$$

Proton helicity = "+"



Proton helicity = "-"



$$A_L^{W+} = \frac{\bar{d}_-^+(x_1)u(x_2) - \bar{d}_+^+(x_1)u(x_2)}{\bar{d}_-^+(x_1)u(x_2) - \bar{d}_+^+(x_1)u(x_2)} = -\frac{\Delta \bar{d}(x_1)}{\bar{d}(x_1)}$$

$$x_1 = \frac{M_W}{\sqrt{s}} e^{y_W}, \quad x_2 = \frac{M_W}{\sqrt{s}} e^{-y_W}$$

Assuming p_T of $W = 0$

$$y_l^{lab} = y_l^* + y_W, \text{ where } y_l^* = \frac{1}{2} \ln \left[\frac{1 + \cos\theta^*}{1 - \cos\theta^*} \right]$$

$$p_T^{\text{lepton}} = p_T^* = \frac{M_W}{2} \sin\theta^*$$

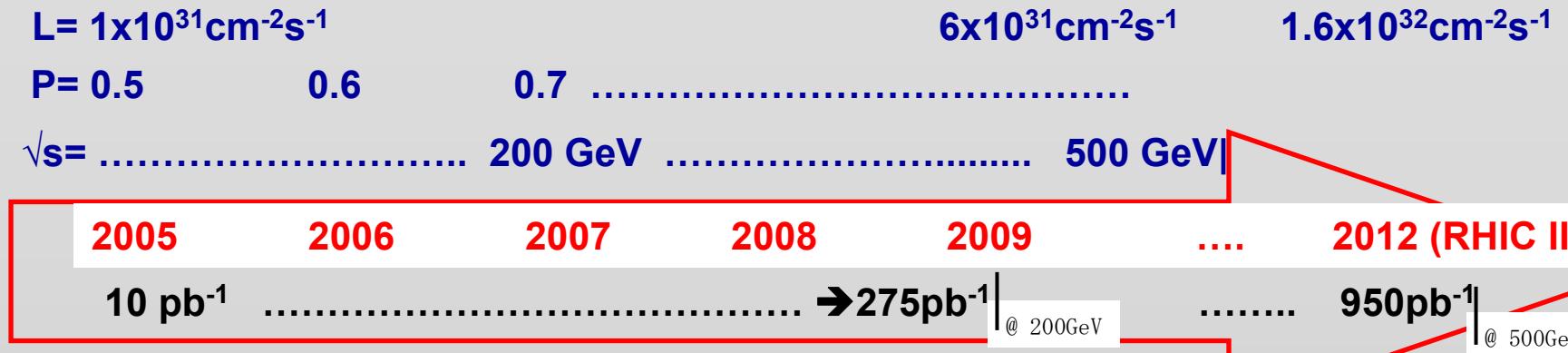
- $\Delta f(x, \mu^2)$: The probability of finding a certain parton type ($f = u, \bar{u}, d, \bar{d}, \dots, g$) with positive helicity in a nucleon of positive helicity, minus the probability for finding it with negative helicity

Polarization	Quarks	Gluons
unpolarized	$q \equiv q_+^+ + q_-^- \equiv q_\uparrow^\uparrow + q_\uparrow^\downarrow$	$g \equiv g_+^+ + g_-^-$
long. polarized	$\Delta q = q_+^+ - q_-^-$	$\Delta g = g_+^+ - g_-^-$
transversity	$\delta q = q_\uparrow^\uparrow - q_\uparrow^\downarrow$	—

Superscripts refer to partons and subscripts to the parent hadron.

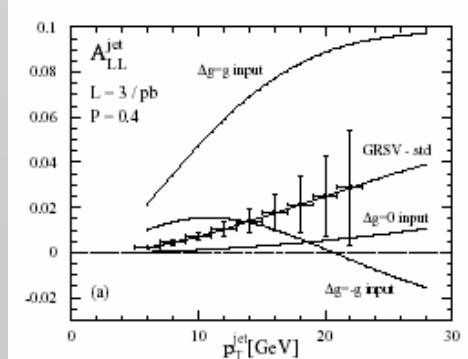
Physics Timeline

see Spin report to DOE <http://spin.riken.bnl.gov/rsc/>

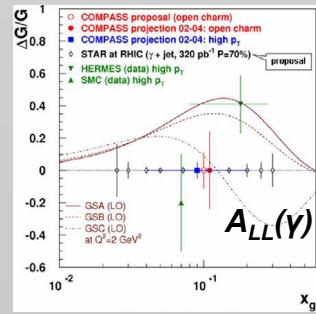
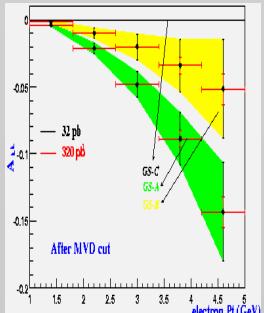


Inclusive hadrons + Jets
 $\sim 25\%$ Transverse Physics
 Charm Physics

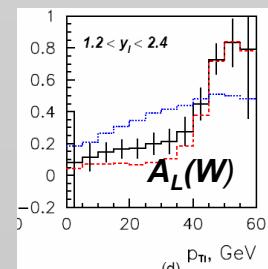
$A_{LL}(\text{hadrons, Jets})$



$A_{LL}(\text{charm})$ direct photons
 bottom physics



W-physics



all units in mm
(except theta)

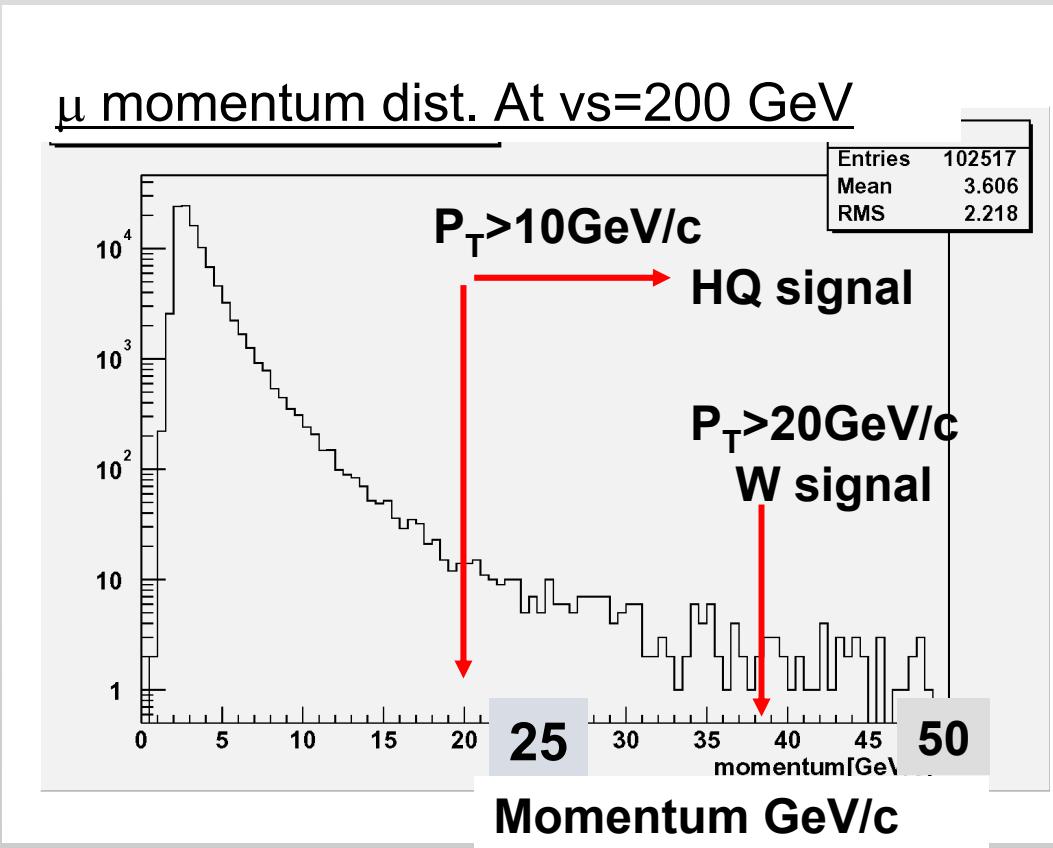
RPC dimensions

	RPC1a		RPC1b		RPC2		RPC3	
theta (deg)	Radius	width	radius	width	radius	width	radius	width
possible					5280.2		5231.7	
	34.36	933.2	773.1	1016.8	842.3	4675.4	3873.2	
ring 8		strips: 181.4 x 12.1 (64)		strips: 197.7 x 13.2 (64)		strips: 467.9 x 60.5 (64)		
	31.60					4207.5	3485.6	
ring 7						strips: 441.0 x 60.5 (58)		
	28.84	751.8	622.8	819.1	678.6	3766.5	2120.3	4991.4
ring 6		strips: 164.3 x 9.7 (64)		strips: 177.7 x 10.6 (64)		strips: 418.2 x 48.8 (64)		4135.0
	26.09					3348.3	2773.9	554.2 x 64.6 (64)
ring 5						strips: 298.9 x 48.8 (57)		3675.9
	23.33	588.7	487.7	641.4	531.4	2949.4	2443.4	528.6 x 64.6 (57)
ring 4		strips: 151.1 x 15.2 (32)		strips: 163.5 x 16.6 (32)		strips: 382.7 x 38.2 (64)		3238.0
	20.57					22566.8	2126.4	507.1 x 50.6 (64)
ring 3						strips: 369.1 x 38.2 (56)		2817.9
	17.81	438.7	363.4	477.9	395.9	2197.7	1820.6	493.3 x 50.6 (56)
ring2		strips: 141.0 x 11.4 (32)		strips: 153.6 x 12.4 (32)		strips: 357.8 x 28.4 (64)		2412.7
	15.06					1839.8	1524.2	474.2 x 37.7 (64)
ring1						strips: 3548.7 x 28.4 (54)		2019.8
	12.30	297.6	246.6	324.3	268.6	1491.1	1235.3	462.1 x 37.7 (54)
possible						1468.4		1926.4
		split gap: ring 4 and 5		split gaps: ring 2 and 3 + ring 6 and 7		no split gaps		1637.0
						no split gaps		

strip length and width consider full acceptance in theta and phi in the octants (i.e. no loss due to readout and boxes)

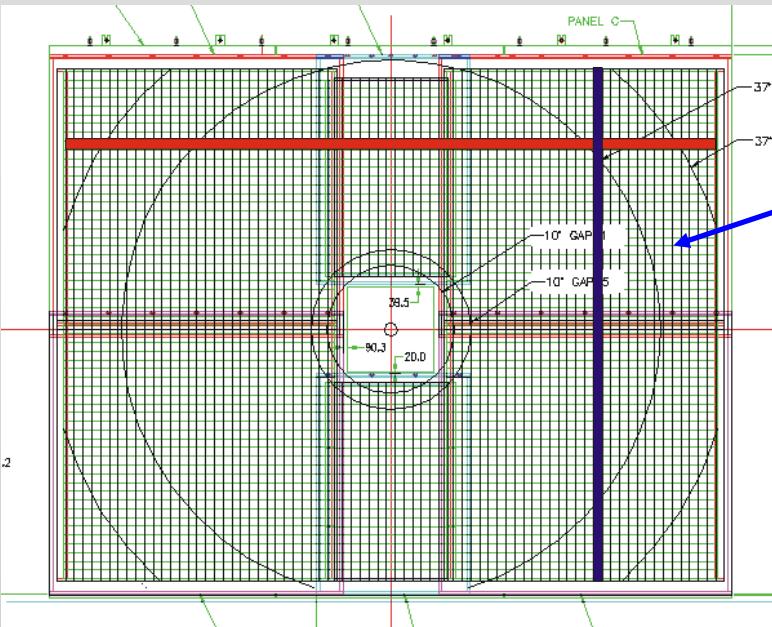
strip width is pre-determined at the outer radius of two paired rings

Trigger Rate and Rejection



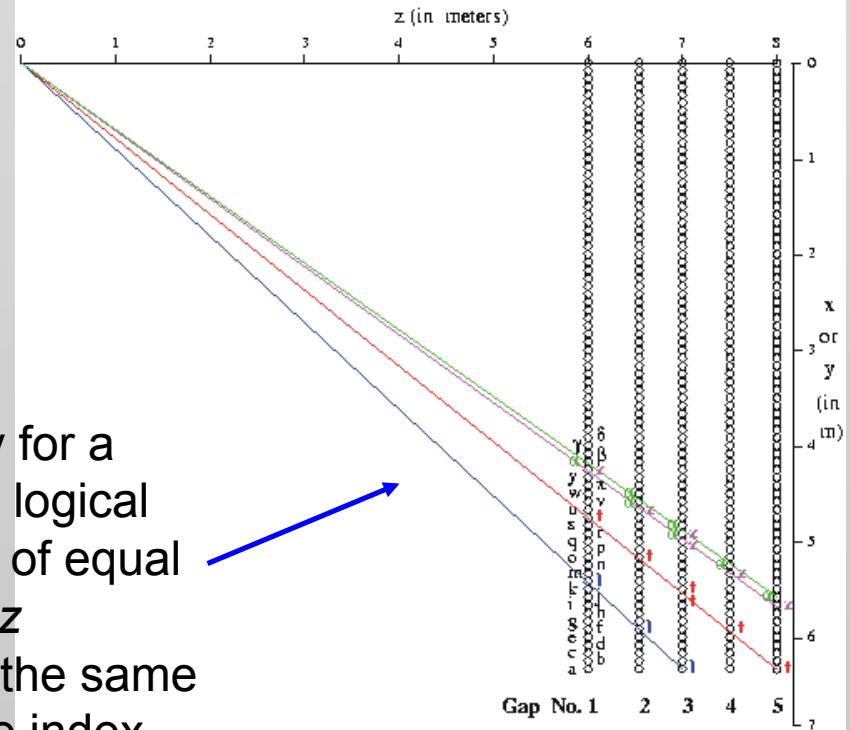
Need Momentum Selectivity in the LVL-1 Trigger!

Existing MuID Level-1 Trigger



Logical tubes formed by OR of physical tubes across panels in each gap.

Rejection Factor ~500 @ 200 GeV/c



The most probable trajectory for a vertex muon striking a gap-1 logical tube is to continue on a path of equal dx/dz (vertical tubes) or dy/dz (horizontal tubes). Tubes w/ the same dx/dz (or dy/dz) get the same index.